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<b>(54) Title:</b> RUBBER-MODIFIED POLYLACTIDE AND/OR GLYCOLIDE COMPOSITION  <b>(57) Abstract</b>  The invention relates to a rubber-modified composition, comprising a matrix and a separate rubber phase, the matrix being based on lactide and/or glycolide (co)polymers, comprising at least 5 wt. % based on the composition of a degradable rubber phase, present as a separate phase, with a glass transition temperature of at most 10 °C, the elongation at break of the composition being at least 120 %. Preferred rubbers are caprolactone or trimethylene carbonate polymers which are blended or block copolymerized with the matrix polymer.		

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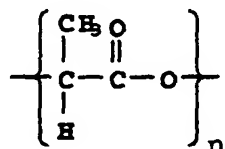
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Title: Rubber-modified polylactide and/or glycolide composition

This invention relates to a rubber-reinforced polylactide and/or polyglycolide composition. Such compositions are known from some recent publications. Polylactide compositions, i.e., synthetic materials based on a matrix of a polylactide,

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are known for their good degradability in the environment. For this reason, a great deal of research has already been conducted into the preparation and modification of such compositions, for instance for packaging purposes.

In view of the good biocompatibility of a number of lactide polymers, a great deal of research has also been conducted into the applicability of such materials in the biomedical field, such as systems for the controlled delivery of pharmaceuticals or as bioresorbable material.

An extensive overview of the state of the art in the field of polylactide compositions is given in the introduction of WO-A 92/04413, which publication is directed to packages of rapid biodegradation. This publication also mentions the possibility of modifying the lactide compositions with a rubber.

Rubber modification of lactide compositions is also described in WO-A 90/01521 of the same applicant as WO-A 92/04413.

In these publications, the starting materials are rubbers based on polyester or copolymers of ethene, propene and various vinyl monomers. Specific mention is made of the use of Hytrel™, a segmented polyester block copolymer of Dupont. The use of such rubbers for the modification of lactide compositions, it is true, leads to an improvement of the impact resistance, but this improvement is not spectacular. From the examples of WO-A 92/04413 it is already evident that with mixtures of different

lactide polymers an improvement of substantially the same magnitude can be achieved. A major disadvantage of the rubber-modified lactide compositions described is that they are hardly biodegradable anymore, if at all, and the biocompatibility leaves to be desired as well. The use of such compositions in the biomedical field and in situations where biodegradability plays an important role is therefore not quite well possible.

The object of the present invention is primarily to provide a polylactide composition which is modified with rubber, which composition possesses clearly improved mechanical properties, such as toughness and elongation at break. A further object of the invention is to provide a polylactide composition which is controllably biodegradable and further possesses good biocompatibility.

Accordingly, the present invention relates to a rubber-modified composition, comprising a matrix and a separate rubber phase, the matrix being based on lactide and/or glycolide (co)polymers, comprising at least 5 wt.% based on the composition of a degradable rubber phase, present as a separate phase, with a glass transition temperature of at most 10°C, the elongation at break of the composition being at least 120%.

Surprisingly, it has been found that such compositions exhibit an excellent combination of properties and can also be suitably used as bioresorbable materials. The articles obtained from the compositions according to the invention combine good impact resistance with good biocompatibility, which renders the materials very suitable for use in the manufacture of various sorts of implants.

An essential aspect of the invention is the nature of the rubber which is used for the modification. Most broadly, it has been found a rubber can be used which is degradable. By this is meant that the rubber phase decomposes in the body or in the environment. The decomposition involved here is preferably a decomposition into substantially non-toxic, water-soluble, preferably cell-metabolizable components.

The decomposition can take place under physiological conditions, under the influence of water, bacteria, enzymes and

the like. Such decomposition can also take place in the environment, for instance in the ground. Further, it is advantageous if the rubber itself is also biocompatible.

Another important aspect of the rubber is that it must give  
5 to the composition an elongation at break of at least 120%. It has been found that if this requirement is satisfied, the composition possesses the advantageous properties which were mentioned in the foregoing. This requirement is more or less  
10 equivalent to the requirement that the rubber have a molecular weight of at least 30 000, more particularly at least 45 000. The upper limit of the elongation at break may be particularly high, it being noted, however, that too high an elongation at break (at 20°C) generally indicates that the composition  
15 threatens to lose the lactide properties and starts exhibiting a rubbery behavior.

According to the invention, both mixtures of rubber and matrix polymer and a rubber phase and matrix polymer chemically bound to each other can be used. The chemically bound rubber phase and matrix polymer is preferred. It is noted that when  
20 blends are used, to obtain the desired elongation at break, the molecular weight of the rubber must generally be higher than in the case where systems are used in which the rubber phase is chemically bonded to the matrix.

According to the invention, the modification of the lactide  
25 matrix with a rubber phase can be carried out in various ways. The rubber can be a homopolymer, a copolymer, or a block copolymer which may or may not be segmented. The monomers from which the rubber phase is made up are chosen from cyclic esters and cyclic carbonates such as  $\epsilon$ -caprolactone and trimethylene  
30 carbonate. Other comonomers can be used as well, one requirement applying to all monomers being that the glass transition temperature must satisfy the requisite value.

When a segmented block copolymer based on hard and rubbery segments is used, it appears that the material possesses two  
35 clearly distinguishable glass transition temperatures. Generally, the rubbery blocks will be present as a separate phase, whilst the hard blocks function as a kind of physical

bonding sites for the matrix. In that case, the nature of the hard blocks should satisfy the requirements of the matrix with regard to composition. It is noted that, according to the invention, preferably two, and not more than two, phases are present in the composition. The three-phase systems disclosed in US-A 4,719,246 are not encompassed by the present invention, since the combination of stereocomplexing of the lactide matrix described therein presents problems with regard to the melting temperature. As appears from the examples of the patent application mentioned, the compositions described therein moreover possess a very low elongation at break, which is an indication of the fact that the properties of the material are not particularly good.

According to a preferred embodiment of the invention, as rubber, a block or star copolymer is used. These polymers are preferably chemically bound to the matrix. This can for instance be suitably realized by preparing, in a first step, the rubber phase from cyclic esters and/or carbonates starting from a polyol as initiator. After completion of the rubber polymerization, an OH-functional rubber is obtained, to which rubber the matrix can be fixedly polymerized. Utilizing this method, a chemical bond is obtained between the matrix phase and the rubber phase in a way giving rise to a particular combination of properties. Each molecule then consists of a rubber core with a number of matrix molecules coupled thereto. These molecules could be represented by the formula  $(B(A_n))$ , wherein B represents the rubber part and A the matrix polymer. n designates the functionality of the rubber and has a value of at least 2. The upper limit is not very critical and can be 10 or more.

The rubbers used are preferably homo and copolymers of cyclic esters which are obtained by ring-opening polymerization. Suitable rubbers are based on trimethylene carbonate,  $\epsilon$ -caprolactone,  $\delta$ -valerolactone, other cyclic lactones and cyclic carbonates, copolymers thereof and copolymers of such monomers with other suitable monomers, such as D- or L-lactide and glycolide. As initiator for the rubber polymerization,

preferably a polyol with two or more hydroxyl groups, or a polyamine is used. Generally, compounds with active hydrogen atoms are suitable. Suitable polyols include 1,6-hexanediol, glycerol, trimethylolpropane, pentaerythritol, myo-inositol and the like.

Such rubbers are amorphous or have a melting temperature below the body temperature. These rubbers are all incompatible with the polylactide/glycolide matrix, so that phase separation takes place. This is a condition for the realization of an increased impact resistance by rubber modification. The amount of rubber to be used is mainly determined by the desired properties. The lower limit is 5 wt.%, since too little improvement of the properties is obtained at lower contents. The upper limit is not critical and will generally be 75 wt.%, since no additional advantages can be achieved at higher contents. A preferred range for the rubber content is 7.5 to 50 wt.%, since in this range an optimum improvement is achieved while the polylactide properties of the matrix are maintained. The upper limit of the rubber content is preferably 30 wt.%.

The preparation of the rubber should be effected in such a manner that the requirement with respect to the elongation at break of the final composition is satisfied. This requirement means that the rubber should have a comparatively high molecular weight ( $M_n$  determined via GPC with polystyrene standard). The preparation of rubbers with a high molecular weight can be effected in the manner known for that purpose, for instance by the use of a catalyst or by choosing the appropriate reaction conditions, such as initiator concentration and reaction time/temperature.

The poly(lactide) matrix to be modified can be a homopolymer of L-lactide, (poly(L-lactide)), or a stereo copolymer of L- and D-lactide, (poly(D,L-lactide)). The L/D ratio determines whether the poly(lactide) is crystalline or amorphous. Copolymers of L/D-lactide with more than 15% D-lactide are amorphous and non-crystallizable. Normally speaking, after compression molding, poly(L-lactide) is semicrystalline but through rapid cooling (quenching) from above

the melting temperature the glass condition can be frozen up, so that the polymer does not crystallize and is amorphous. However, in the course of time or during degradation, possibly this material may still crystallize. Copolymers with less than 15% D-lactide are substantially amorphous after compression molding, but also crystallizable.

For use in biomedical applications, non-crystallizable polymers are preferred, since the crystalline residual products possibly give rise to inflammatory reactions in the body during degradation. The major disadvantage of these amorphous poly(lactides) is the much lower impact resistance compared with the higher crystalline materials. Rubber modification with degradable rubbers is a way of increasing impact resistance. Increasing the toughness and the impact resistance of these poly(lactides) according to the invention can be realized by the synthesis of star-shaped block copolymers of lactide (L- or L/D-lactide) and rubber monomers, as well as by making blends (physical mixtures) of poly(lactide) (L- or L/D-copolymers) and rubber polymers.

The preparation of the lactide and/or glycolide matrix polymers can be effected in known manner, for instance as described in Dutch Patent Application 9000959 or European Patent Application 108,635, the contents of which publications are incorporated herein by reference. In contrast with the disclosure of EP-A 499,204, according to the present invention, no fiber material is used as starting material, but the composition is prepared from monomers by polymerization thereof. It is further noted that the polymerization of the rubber can also be effected in the manner as described in the first-mentioned patent publications. In that case, however, no star polymers but linear polymers are obtained.

The toughness of polymers is an important property, since it represents the amount of energy the material can absorb before break occurs. A measure of the toughness is the area under a force-elongation curve obtained when the tensile strength of a material is measured. In this connection, a high elongation at break is essential to a high toughness. Another



method is to measure the impact resistance of a material, by striking a test rod with a hammer until break occurs. The energy absorbed during the breaking process divided by the original surface area is the impact resistance. Compared with the force-elongation experiment, the speed of an impact test is considerably higher, so that these values rarely correspond. Impact resistance measurements are performed in accordance with different test standards. Most commonly used is the Izod-notched test (ASTM D-256), whereby the impact resistance is measured on test rods of a depth of 12.7 mm. The unit in which the impact resistance is then expressed is ftlb/inch per inch of notch, or, in SI units, J/m per inch of notch. Because the depth of the rod is constant it can be converted to an energy per unit area J/m<sup>2</sup>.

Measurements on the rubber-modified materials in accordance with this standard enable a comparison with much used commercially available plastics. Our impact resistance measurements were typically carried out in accordance with DIN 53453 (Dynstat unnotched), the advantage of this method being that only small test pieces are necessary. The impact strength is expressed in J/m<sup>2</sup>. In several cases, measurements were performed in accordance with both standards. The impact strength measured on a notched test piece is always lower than that measured on an unnotched test piece. Our measurements on crystalline and amorphous compression molded poly(lactide) clearly show the influence of crystallinity on impact resistance. Amorphous poly(lactide), whether quenched poly(L-lactide) or a copolymer of 85/15 L/D-Lactide, is significantly less impact resistant than crystalline poly(L-lactide).

Both the amorphous non-crystallizable and the crystalline poly(lactides) can be rendered considerably tougher by the rubber modification according to the invention.

ABA block copolymers of 95/5 L/D-lactide with various rubbers possess a much higher impact resistance than the non-modified material (20% rubber even gives no break anymore in the Dynstat impact resistance test). The much higher elongations at break (some hundreds of percents) also show that these materials

are particularly tough. A poly(95/5 L/D-lactide) star-block copolymer with a degradable rubber has a particularly high elongation at break and shows no break in the Dynstat impact resistance test. Copolymers of L- and D-lactide can be rendered  
5 impact resistant by physically mixing the poly(lactide) with an L-lactide/ $\epsilon$ -caprolactone rubber. The impact resistance increases with increasing rubber content and is higher for the copolymers with little or no D-lactide. Amorphous 85/15 L/D lactide copolymers can be rendered impact resistant. Both star-block  
10 copolymers and ABA block copolymers and blends with various rubbers or ABA block copolymers yield tough materials which no longer break in the Dynstat impact test at a rubber percentage of approximately 20%. It is remarkable in the comparison of materials modified with equal amounts of the same rubber that  
15 the elongation at break of blends is lower than that in block copolymers or star-block copolymers, which points to an important role of the extent of bonding between the rubber part and the lactide matrix. This is the case both for crystalline 95/5 and amorphous 85/15 L/D-lactide modified polymers.

20 The materials according to the invention can be used in all kinds of fields. These uses lie especially in the field where the biological and/or degradation properties are important. Examples of uses include those in the field of packaging materials and in the biomedical field. The materials can be  
25 processed into sheets, fibers, articles, hoses, disposables, and the like. The conventional additives can be incorporated in them and processing takes place in the manner known for such polymers.

Possible uses for the materials according to the invention  
30 in the biomedical field include their use as drug-release means, nerve conductors, artificial veins, wound covering, artificial skin, sutures, surgical membranes, orthopedic implants and the like.

The invention will now be elucidated in and by a number of  
35 examples, without being limited thereto.

### EXAMPLES

While employing a number of different starting materials and reaction conditions, a number of rubber-modified synthetic materials were prepared.

Unless otherwise stated, the various materials were polymerized in the following manner.

I. Lactide was polymerized by adding an amount of  $10^{-2}$  mol.% catalyst (Sn-octoate: I<sup>a</sup>, tin(II)-bis (2,4-pentanedionato-O-O': I<sup>b</sup>) to a melt of the relevant lactide or mixture with lactide at 110°C and polymerizing at this temperature until the polymerization was completed or substantially completed. This method was also followed for the homopolymerization of trimethylene carbonate and  $\epsilon$ -caprolactone.

II. Block and star-shaped copolymers were obtained by adding a polyol to a melt of a relevant monomer and polymerizing for 12 to 96 hours at 110 to 150°C. Following this polymerization, a melt of the matrix monomers was subsequently added to the rubber formed, where upon polymerization was continued.

The results of the various tests are included in the following Table. In Examples 1-3, a star-rubber based on pentaerithrytol was used, whilst Example 5 is based on an ABA rubber block mixed with the matrix material.

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TABLE

Example	Rubber	Matrix L/D	Preparation	Dynstat kJ/m <sup>2</sup>	Izod J/m	$\sigma$ #	M <sub>n</sub> # 10 <sup>-3</sup>	Elongation at break %
1	20% TMC/ $\epsilon$ -Cl	85/15	II*	(CH <sub>2</sub> Cl)	g	25.9	73	625
2	20% TMC/ $\epsilon$ -Cl	95/5	II*	(toluene)	g	34.5	73	290
3	15% $\epsilon$ -Cl/ $\delta$ -VL	85/15	II*	(melt)	g	22.1	120	400
4	20% TMC	85/15	II <sup>b</sup>	(melt)	g	36.9	65.1	210
5**	21% TMC	85/15	II+Ia	(melt)	g	36.0	41.1	280
6	20% TMC/ $\epsilon$ -Cl	85/15	Ia	(blend)	g	36.0	800	130
7	34% $\epsilon$ -Cl/L-lactide	100/0	Ia		g	30.8	250	1500
8	20% TMC- $\epsilon$ -Cl	85/15	II		446	41.4	46.5	120
9#	-	100/0	Ia	10.0	83.3	72.3		7.1
10#	-	85/15	Ia	5.0	41.0	64.5		6.4

# tensile strength MPA

\* Polymerized in the presence of pentaerythritol

\*\* Rubber block copolymer mixed with polylactide matrix

# Comparative (M<sub>n</sub> matrix > 50,000)

g no break

## Rubber block relative to polystyrene standard

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CLAIMS

- 1 A rubber-modified composition, comprising a matrix and a  
separate rubber phase, the matrix being based on lactide and/or  
5 glycolide (co)polymers, comprising at least 5 wt.% based on the  
composition of a degradable rubber phase, present as a separate  
phase, with a glass transition temperature of at most 10°C, the  
elongation at break of the composition being at least 120%.
2. A composition according to claim 1, wherein the rubber is  
10 based on trimethylene carbonate.
3. A composition according to claim 1 or 2, wherein the rubber  
is based on  $\epsilon$ -caprolactone.
4. A composition according to claims 1-3, wherein the rubber  
is selected from the group consisting of poly(trimethylene)  
15 carbonate, copolymers of L-lactide and  $\epsilon$ -caprolactone, glycolide  
and  $\epsilon$ -caprolactone, trimethylene carbonate and  $\epsilon$ -caprolactone,  $\delta$ -  
valerolactone and  $\epsilon$ -caprolactone, as well as rubbers based on a  
polyol and one or more of the above-mentioned components.
5. A composition according to claims 1-4, wherein the lacride  
20 matrix has been obtained by polymerization in the presence of a  
star or block rubber.
6. A composition according to claims 1-4, wherein the  
polylactide matrix and biodegradable rubber are mixed with each  
other.
- 25 7. A composition according to claims 1-6, wherein the  
polylactide matrix consists of poly(L-lactide).
8. A composition according to claims 1-6, wherein the  
polylactide matrix is substantially amorphous and consists of a  
copolymer of L- and D-lactide with at least 15% D-lactide.
- 30 9. A composition according to claims 1-6, wherein the  
polylactide matrix is substantially amorphous but crystallizable  
and is based on a copolymer of D-lactide and L-lactide with less  
than 15% D-lactide.
10. Use of the composition according to claims 1-9 for medical  
35 applications.
11. Articles manufactured in whole or in part from the  
composition according to claims 1-9.

12. A method of preparing a composition according to claims 1-9, comprising polymerizing one or more rubber forming monomers in the presence of a compound comprising at least one active hydrogen, so as to form a functional rubber, followed by adding  
5 the matrix polymers to the functional rubber and polymerizing same in the presence of said rubber.
13. A method according to claim 12, wherein a polyol is used as compound comprising at least one active hydrogen.